

System of Systems Engineering and Family of Systems Engineering from a Standards, V-Model, Dual V-Model, and DoD Perspective

Systems and Software Technology Conference

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Introduction – My Perspective

J Clark

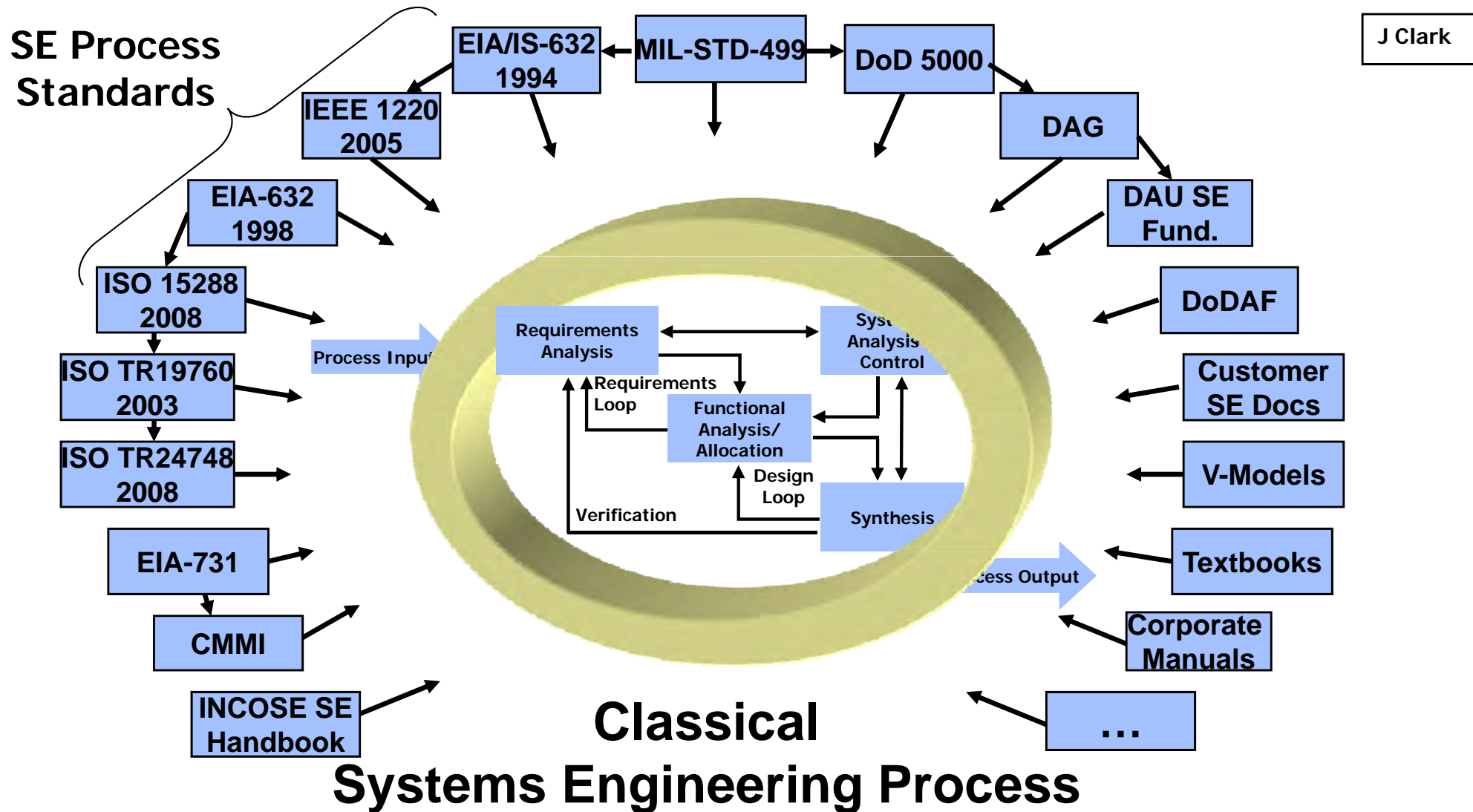
- System of Systems Engineering (SoSE) and Family of Systems Engineering (FoSE) continue to be two of the least well-understood SE disciplines.
- Knowledge of the SE process standards, the V-Model, and particularly the 3-dimensional Dual-V Model, significantly aid this understanding, including the relationship between SE, SoSE, and FoSE.
- The goals of this presentation are to:
 - Define SoS, SoSE, and FoSE from an SE Standards perspective
 - Describe the original V-Model and the Dual-V Model
 - Show how to apply these SE Standards and V-Models to a system, to SoSs, and to FoSs
 - Encourage and challenge the participants to understand, select, tailor, and apply these SE standards and V-Models to complex SoSs and FoSs
- Individuals may have an understanding of portions of SE, SoSE, and FoSE based on other sources. The SE Standards, V-Model, and Dual-V Model provide a more complete and common understanding.

Introduction – My Perspective (cont)

J Clark

- SoSE versus SE is currently debated in the literature and at conferences such as this
- Question: Is engineering a SoS really any different from engineering an ordinary system?
 - Some believe SoSE is “different” from SE, the SE processes are inadequate or insufficient for SoSE, and additional processes are needed.
 - Others, like me, believe the SE processes as documented in the SE standards: IEEE 1220, EIA/IS-632, EIA-632, ISO 15288, and the guide: ISO TR 19760, are a necessary and sufficient set of processes for SoSE, and no additional processes are needed. Otherwise, please help us revise these standards.
- In my opinion (based on reading, comparing, understanding, teaching, revising, tailoring, and applying the SE standards):
 - There is only one classical SE process
 - There are multiple views of this one classical process
 - These multiple views provide a comprehensive view as shown in the next chart. By understanding them, you get a comprehensive view.

Systems Engineering Views – My Perspective



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Multiple views provide a comprehensive view.

What is Different About SoSE and FoSE? – My Perspective

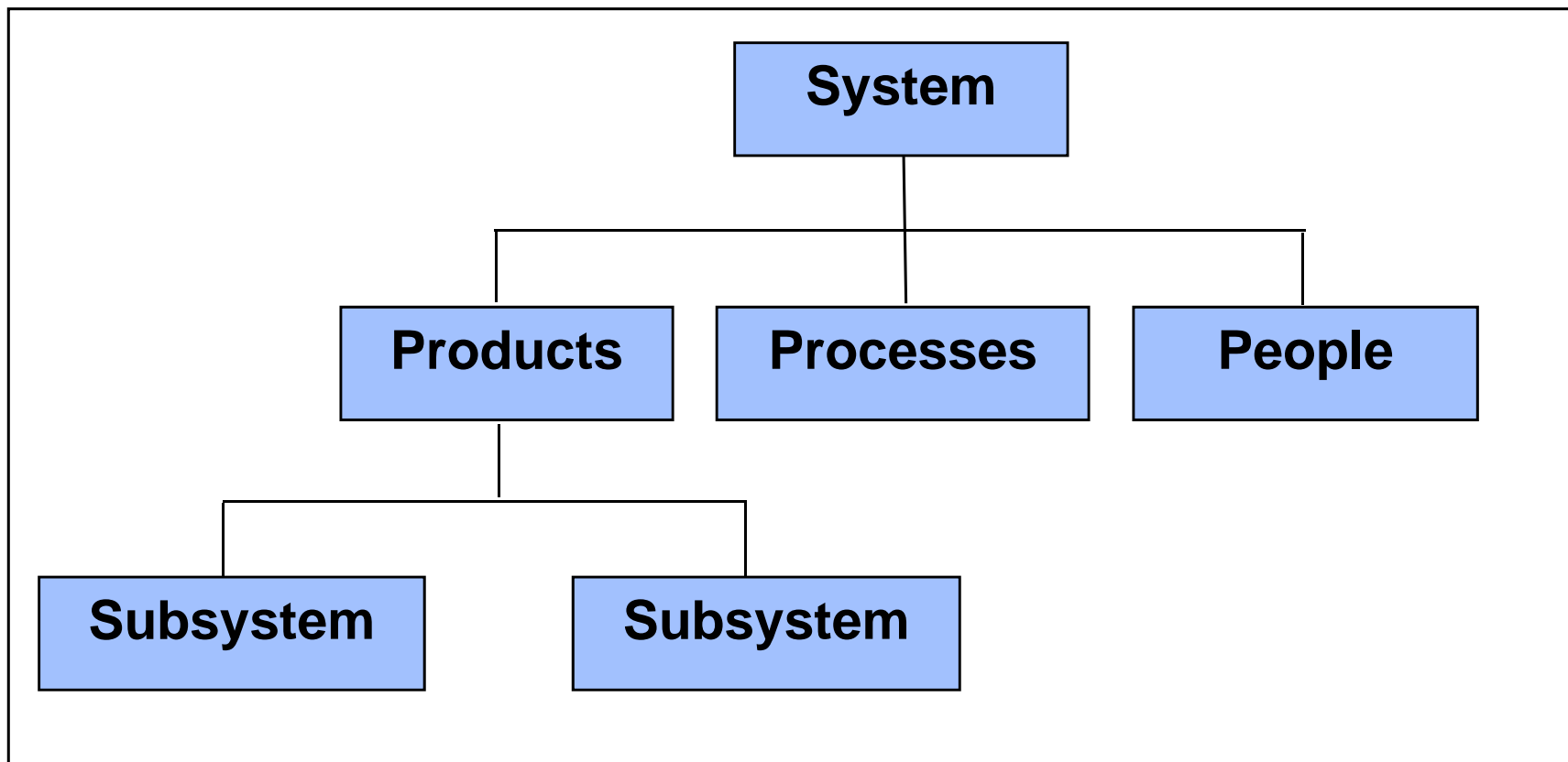
J Clark

- The management (e.g., acquisition) processes are inadequate, not the technical (SE Standards) processes:
 - There is no god (no overall Program Manager) of a SoS or FoS
 - Acquisitions are stovepipes (single systems, not SoS or FoS)
 - Systems are directed to “integrate” with other systems, often after fielding
 - Suppliers don’t cooperate with each other in FoSE (they believe it’s not in their best interest)
 - Acquirers don’t cooperate with each other for the same reason
 - FoSE costs more up-front to develop for re-use (but saves much more later)
 - Interoperability is hampered by lack of SoSE and FoSE

Building Block - Used in SE Standards

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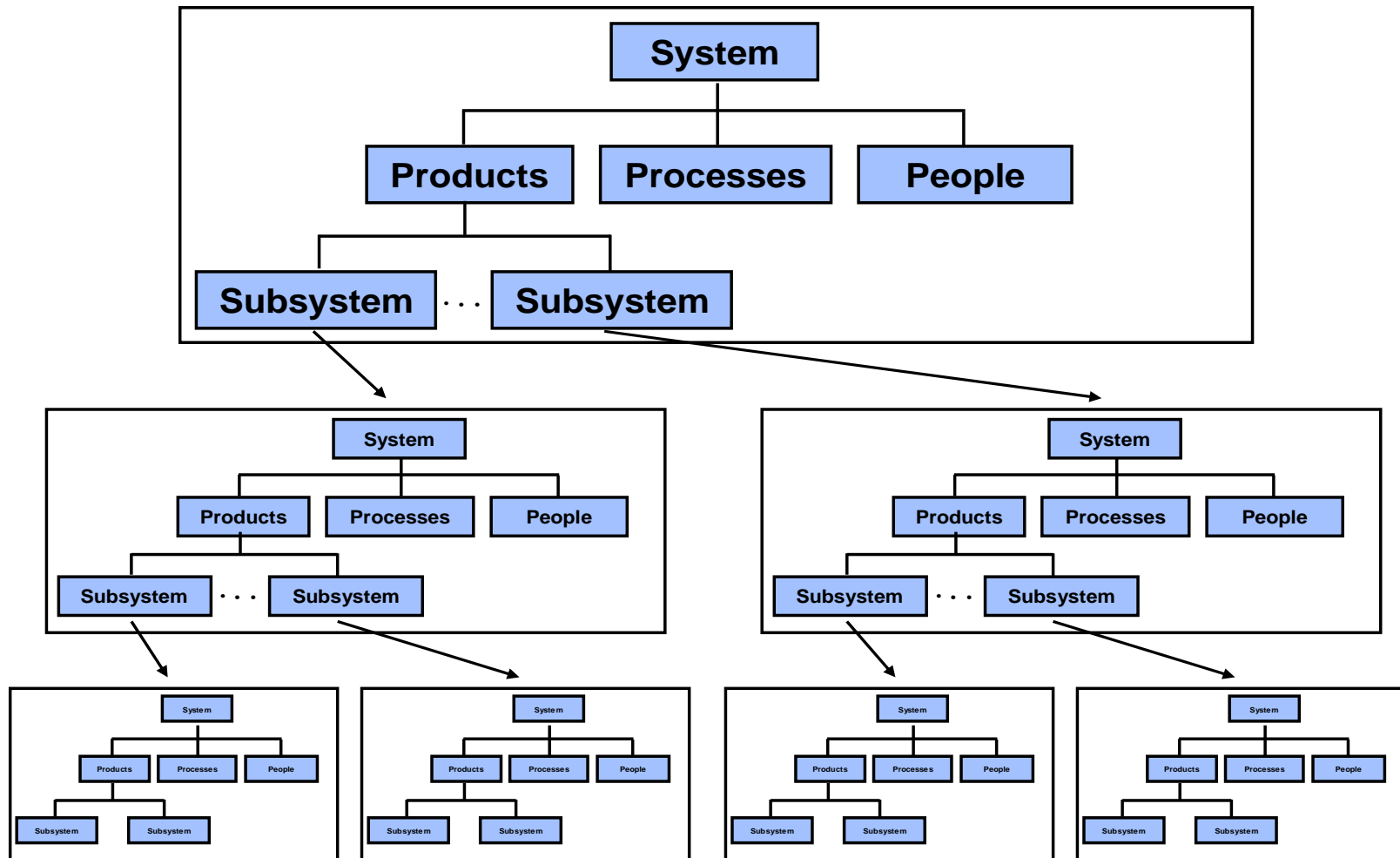
System Building Block



Building Block – Used in SE Standards (cont)

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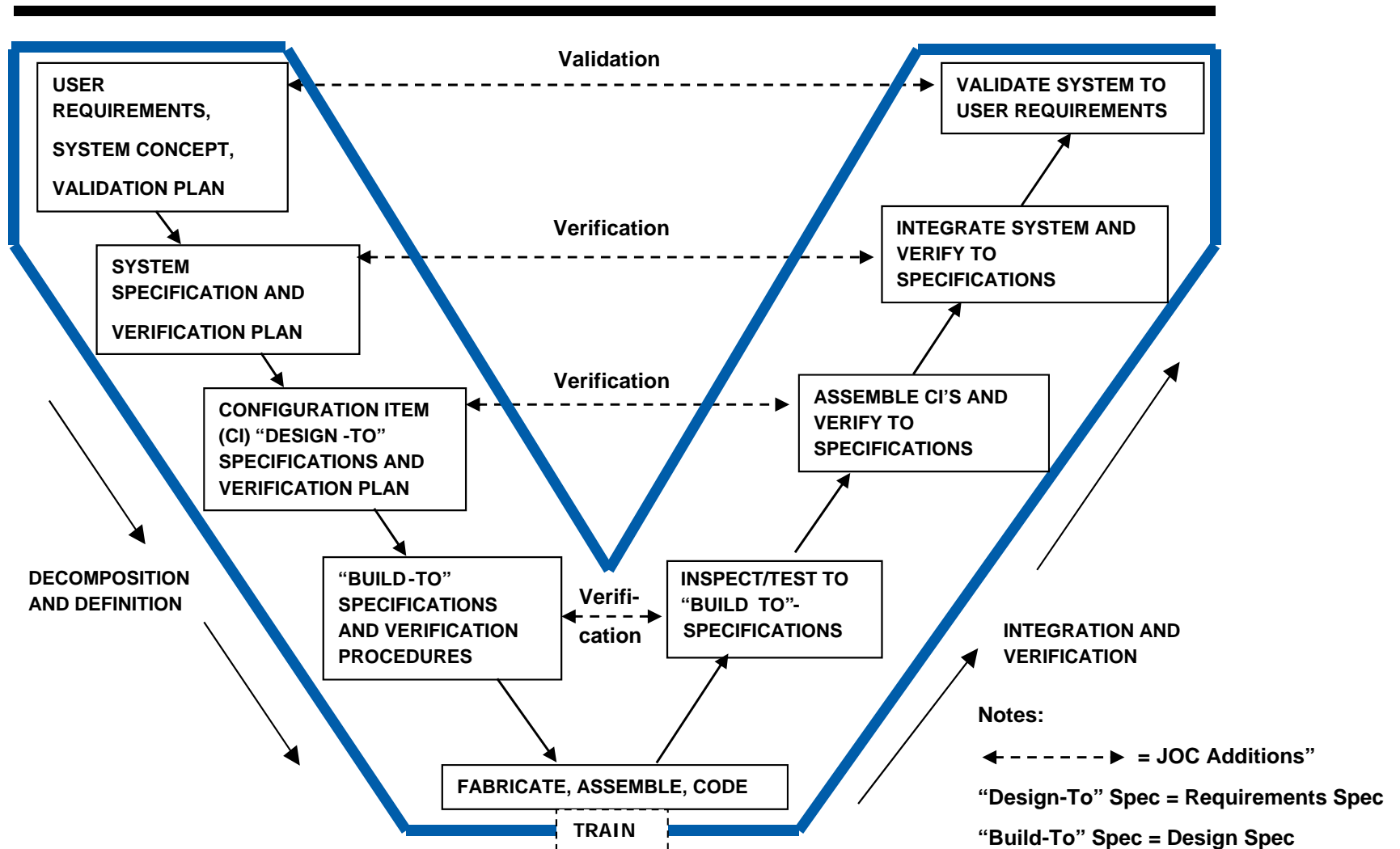
System of Systems Building Blocks



V-Model

Original V-Model (Entity V-Model)

K Forsberg



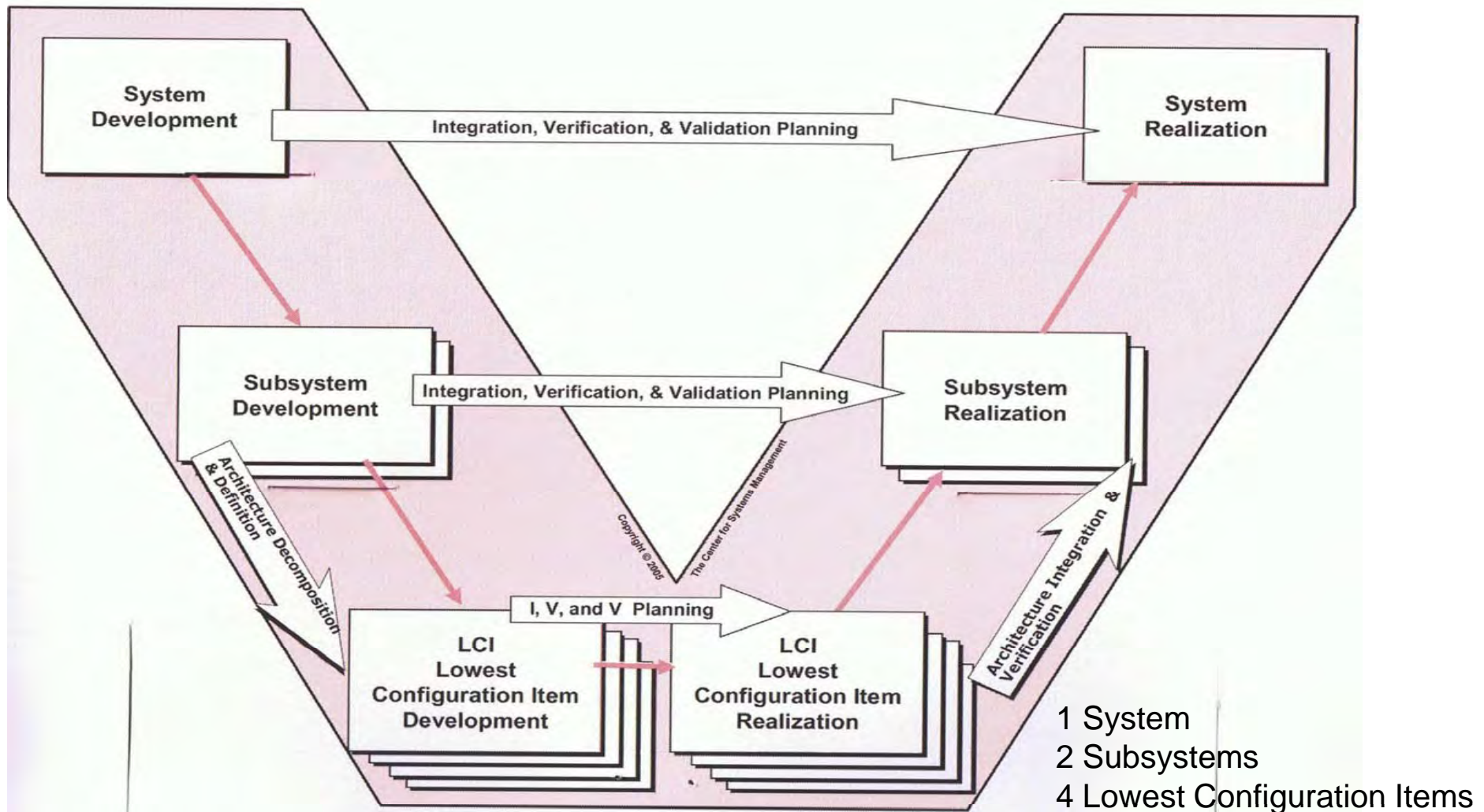
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V-Model (cont)

Dual V-Model Example Details (1 System V)

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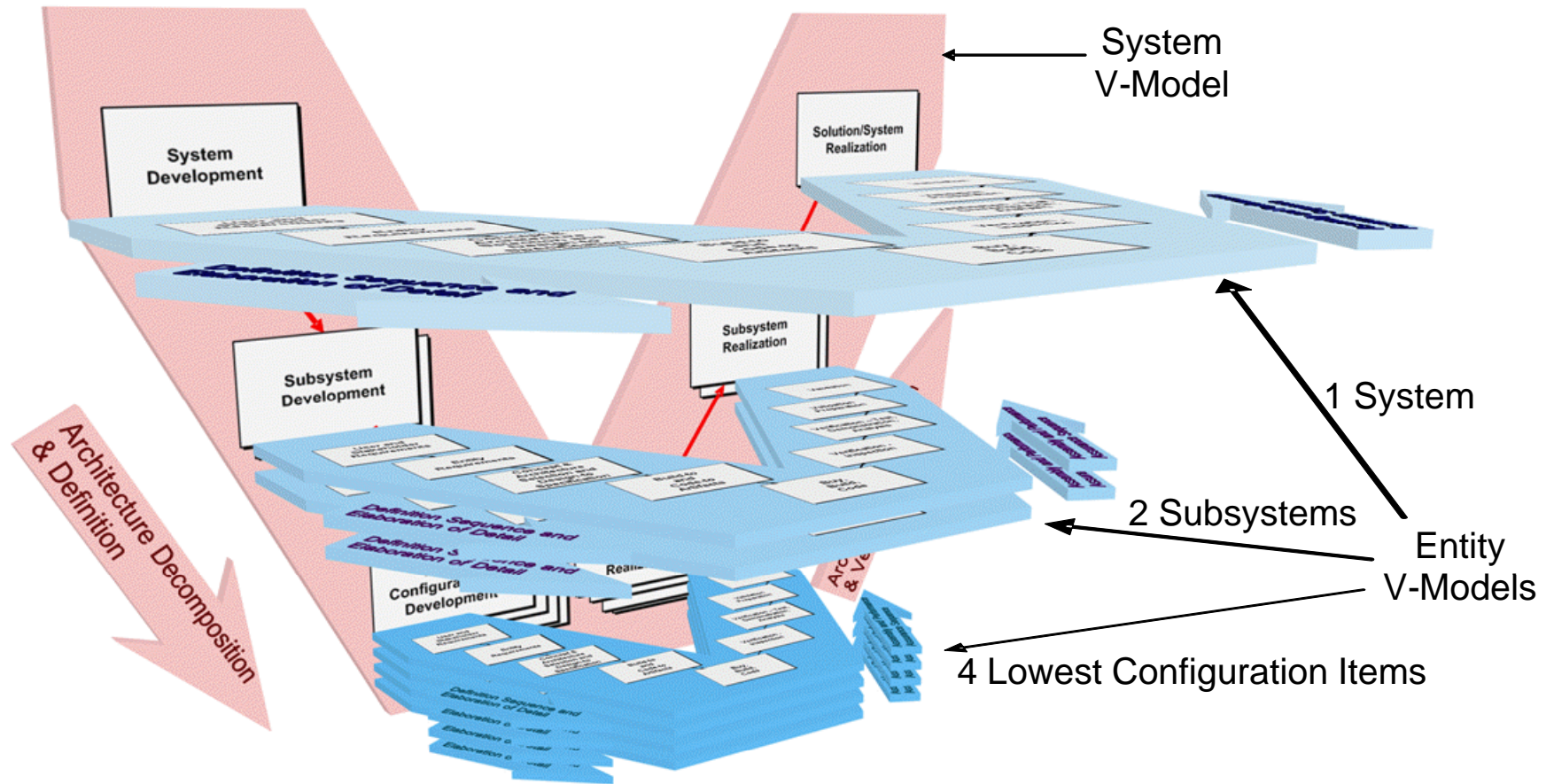
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V-Model (cont)

Dual V-Model Example

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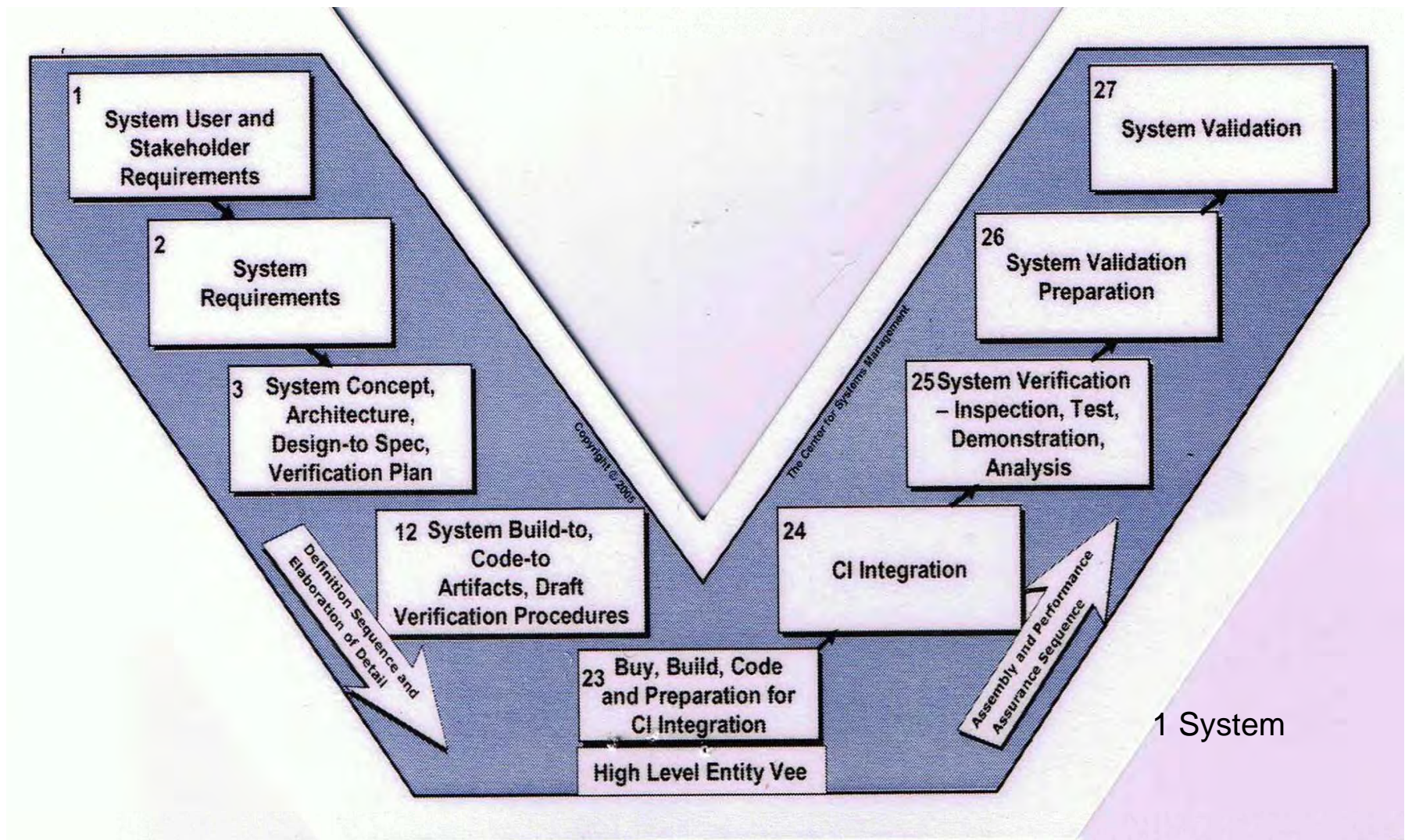
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V-Model (cont)

Dual V-Model Example Details (1 System Entity V)

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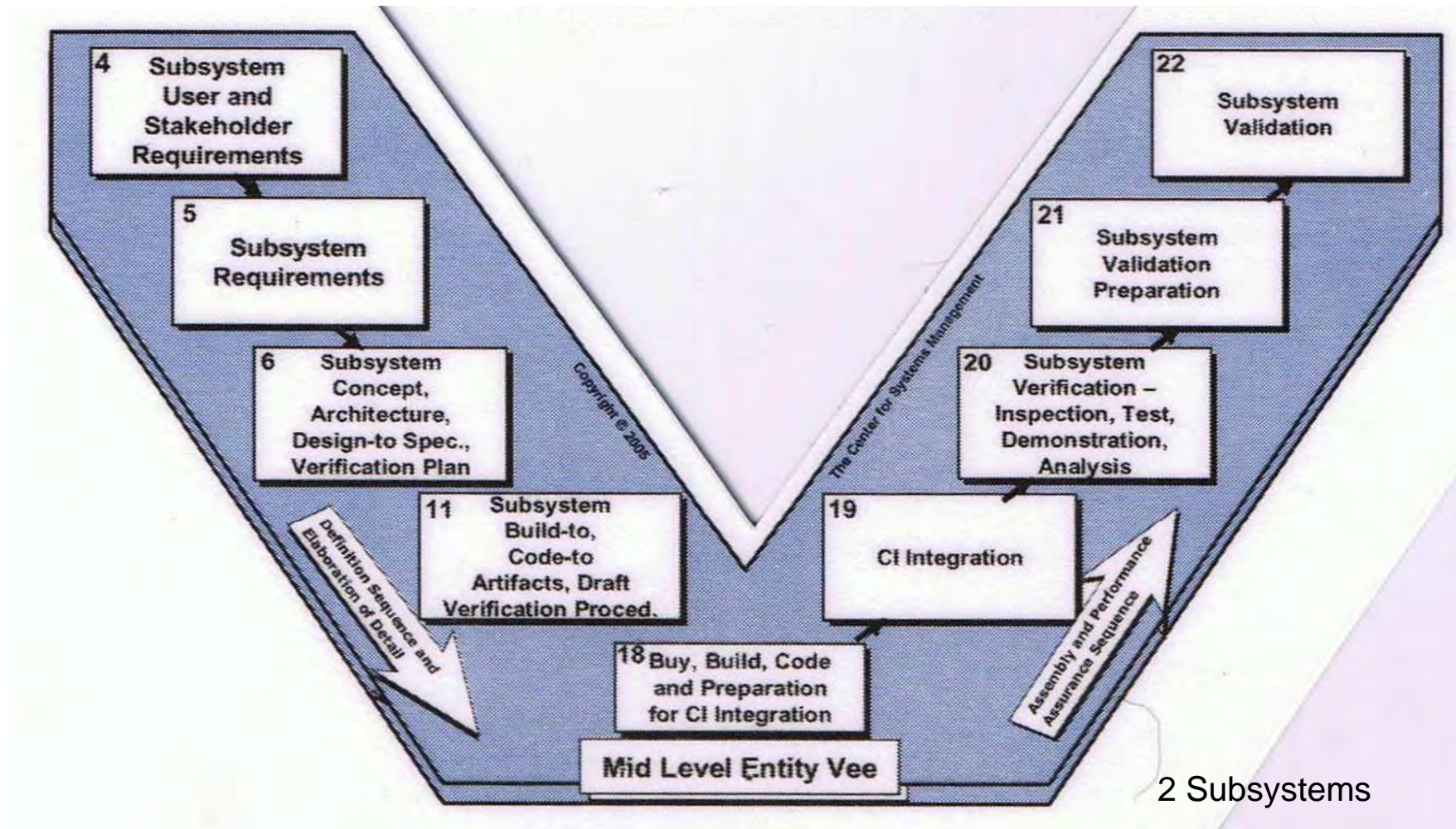
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Dual V-Model Example Details (2 Subsystem Entity Vs)

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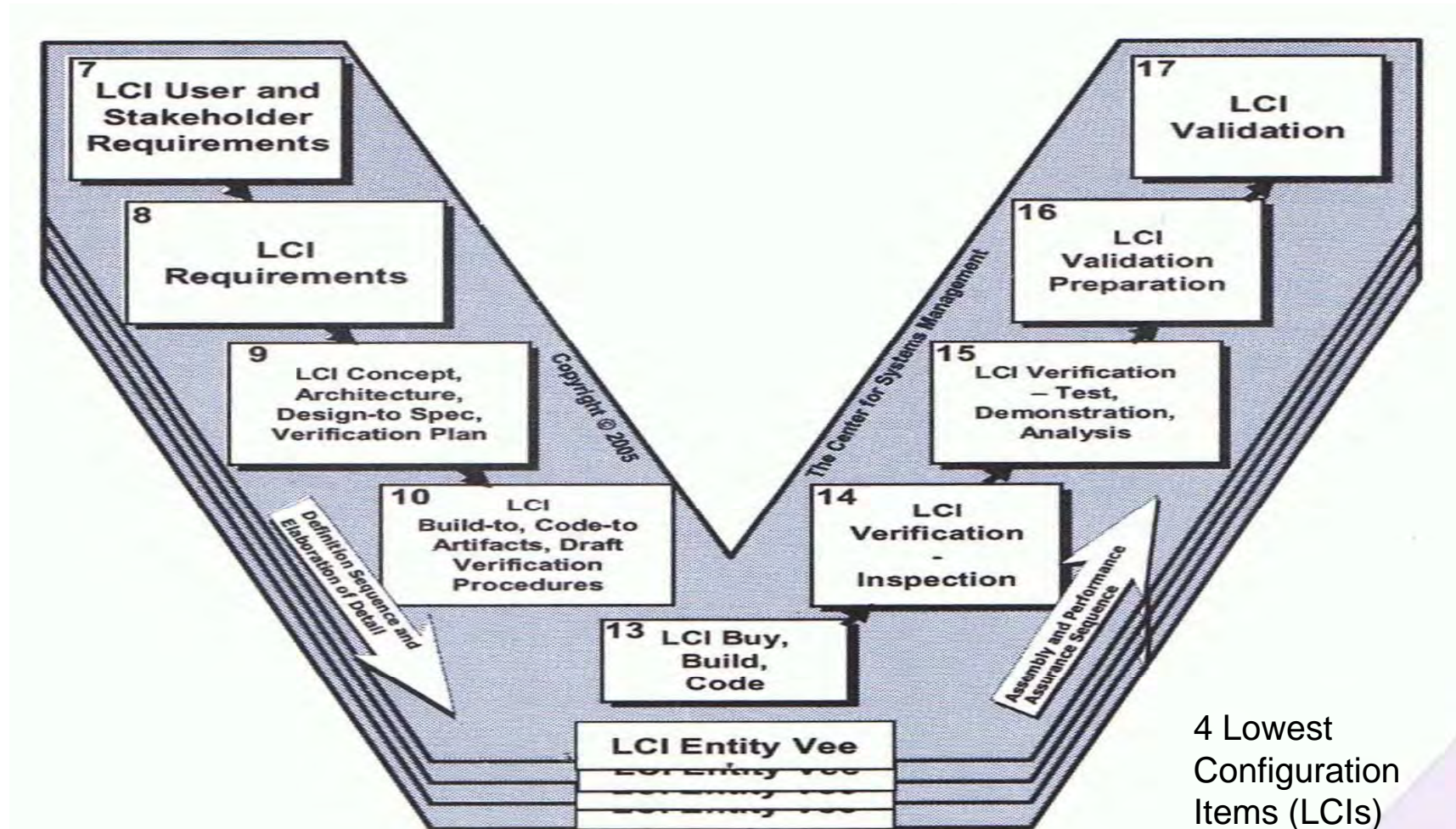


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V-Model (cont)

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Dual V-Model Example Details (4 Lowest Configuration Item Entity Vs)



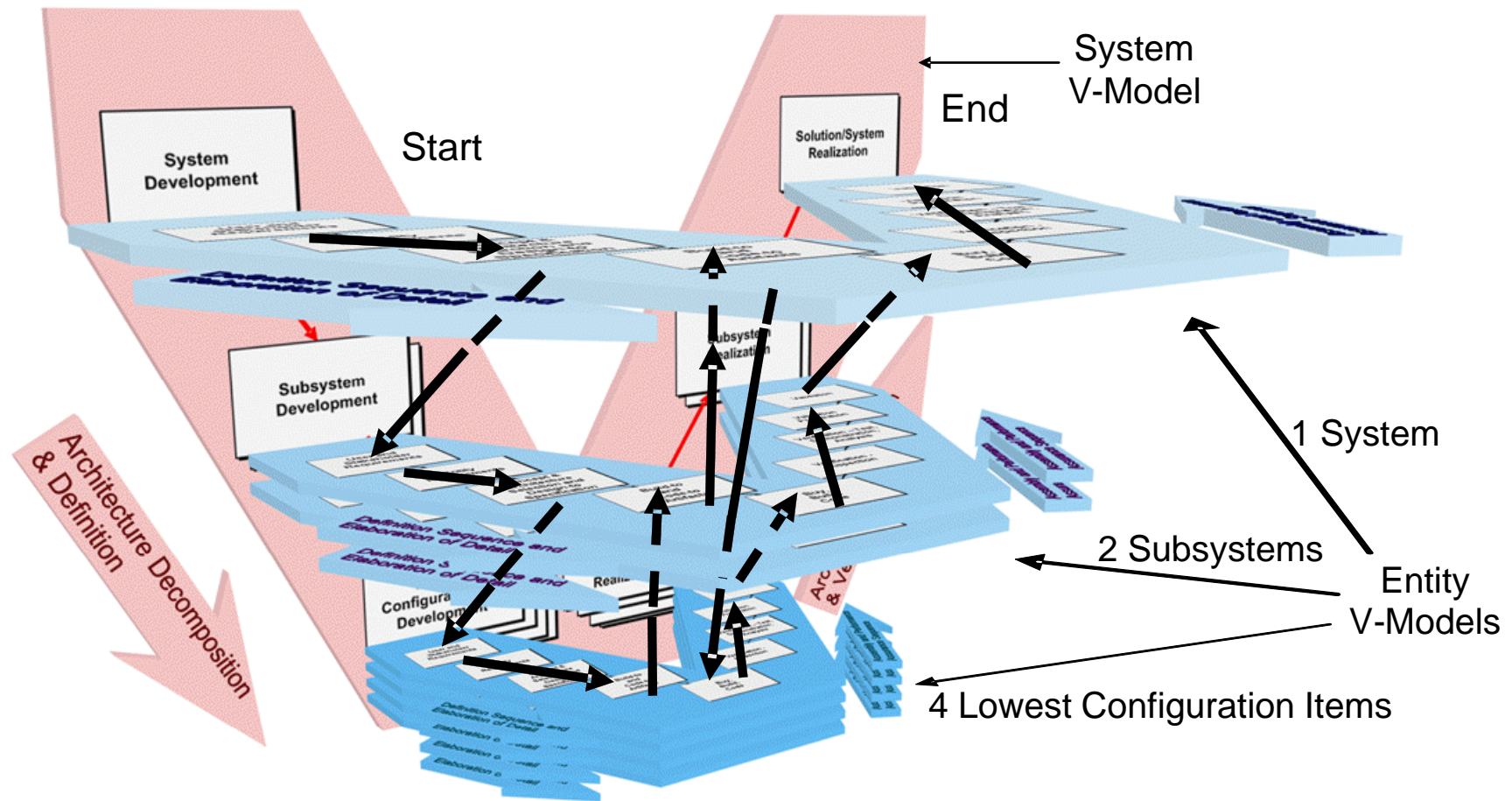
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V-Model (cont)

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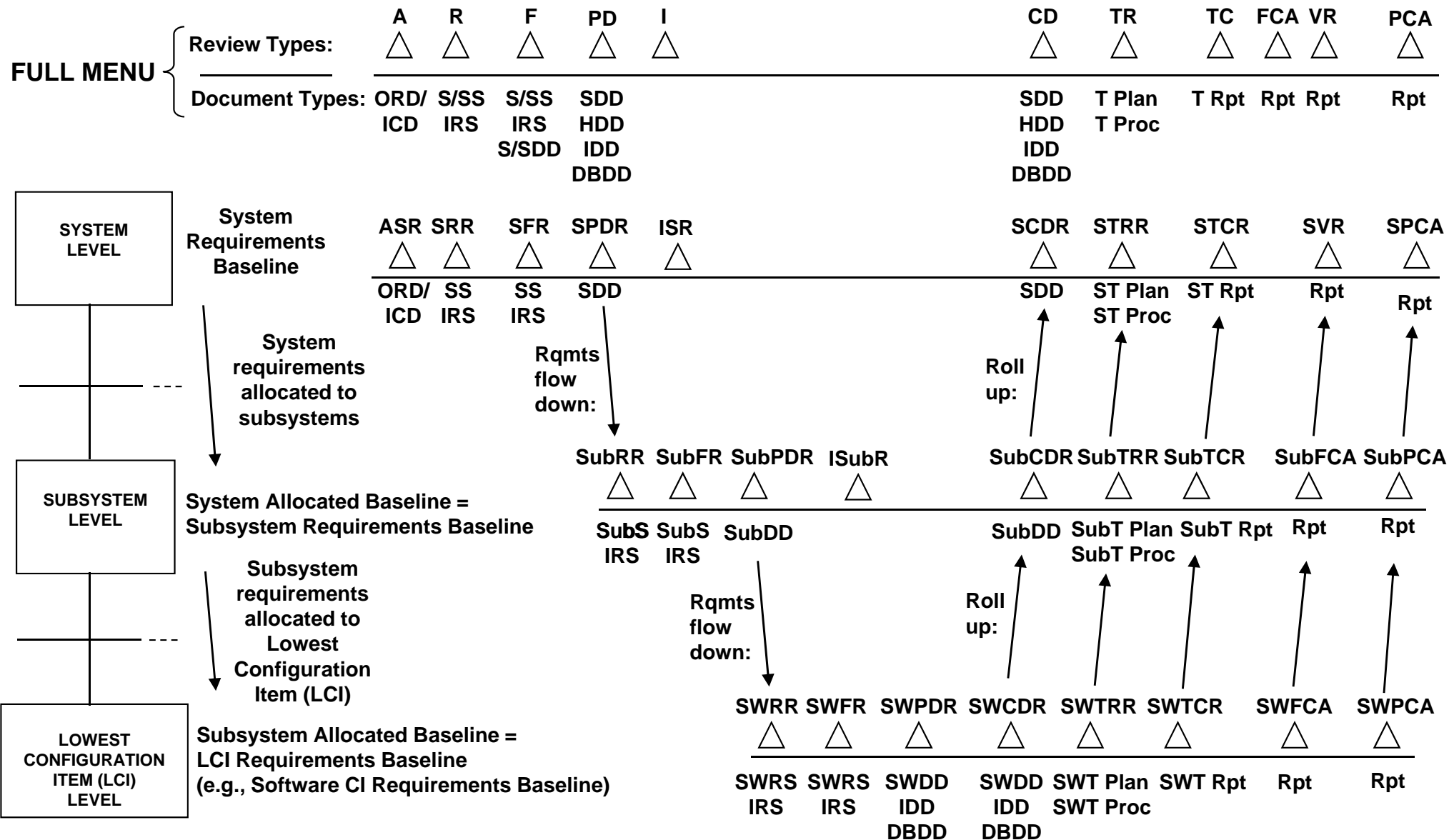
Dual V-Model Example Sequence



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Baselines, Documents, and Reviews for a System – My Perspective

J Clark



Simple Definitions of SoS and FoS – My Perspective

J Clark

- SoS: The sum of the whole is **greater** than the sum of the individual parts
 - The parts are integrated (i.e., have interfaces)
 - The parts may or may not be members of a common domain (such as a product line, for example: surface ship radars)
- FoS: The sum of the whole is **equal** to the sum of the individual parts
 - The parts are not integrated
 - The parts are members of a common domain (such as a product line)

U.S. Department of Defense's Definitions of SoS

Defense Acquisition Guidebook (DAG)-2006 Definition of SoSE

- Deals with planning, analyzing, organizing, and integrating the capabilities of a mix of existing and new systems into a SoS capability **greater than the sum of the capabilities of the constituent parts.**
- **SoSs should be treated and managed as a system in their own right, and should therefore be subject to the same systems engineering processes and best practices as applied to individual systems.**
- Differs from the engineering of a single system. The considerations should include the following factors or attributes:
 - Larger scope and greater complexity of integration efforts;
 - Collaborative and dynamic engineering;
 - Engineering under the condition of uncertainty;
 - Emphasis on design optimization;
 - Continuing architectural reconfiguration;
 - Simultaneous modeling and simulation of emergent System of Systems behavior; and
 - Rigorous interface design and management.

U.S. Department of Defense's Definitions of SoS (cont)

Systems Engineering Guide for Systems of Systems, v1.0, 2008
(References the **Draft** Defense Acquisition Guidebook (DAG)-**2008**
(**not issued in 2008**) for the Definition of a SoS)

- A SoS is a set or arrangement of systems that results when **independent** and useful systems are **integrated** into a larger system that delivers unique capabilities.
- Both **individual systems and SoS conform to the accepted definition of a system** in that each consists of parts, relationships, and a whole that is greater than the sum of the parts; however, **although an SoS is a system, not all systems are SoS.**
- Consistent with the DoD transformation vision and enabling net-centric operations (NCO), SoS may deliver capabilities by combining multiple collaborative and autonomous-yet-interacting systems.
- The mix of systems may include existing, partially developed, and yet-to-be-designed independent systems.

U.S. Department of Defense's Definitions of SoS (cont)

Systems Engineering Guide for Systems of Systems, v1.0, 2008
(References the Draft Defense Acquisition Guidebook (DAG)-2008
(not issued in 2008) for the Definition of a SoS)

- The SE Guide to SoS identifies 3 new SoS SE "roles":
 - Translating Capability Objectives
 - Understanding Systems & Relationships
 - Monitoring & Assessing Changes
- My Opinion: It is unclear to me why these three SoS SE roles are really "new." In my opinion they are included in the 16 technical and technical management processes defined in the DAG chapter 4, and are included in the SE Standards, V-Model, and Dual-V Model on which the DAG chapter 4 is based.

U.S. Department of Defense's Definitions of SoS (cont)

Interim Defense Acquisition Guidebook (DAG)-**2009** Definition of SoS and SoSE (Reference: **Systems Engineering Guide for Systems of Systems, v1.0, 2008**)

- A SoS is defined as a set or arrangement of systems that results from **independent** systems **integrated** into a larger system that delivers unique capabilities.
- **Both systems and SoS conform to the accepted definition of a system,** in that each consists of parts, relationships, and a whole that is greater than the sum of its parts.
- **While a SoS is a system, not all systems are SoS.**
- SoS engineering deals with planning, analyzing, organizing, and integrating the capabilities of a mix of existing and new systems into an SoS capability greater than the sum of the capabilities of the constituent parts.
- SoS engineering is an activity that spans the entire system's life cycle; from pre-Milestone A through Disposal.

U.S. Department of Defense's Definitions of SoS (cont)

Interim Defense Acquisition Guidebook (DAG)-**2009** Definition of SoSE

Types of Systems of Systems

(Reference: Systems Engineering Guide for Systems of Systems, v1.0, **2008**)

Type	Definition
Virtual	Virtual SoS lack a central management authority and a centrally agreed upon purpose for the SoS. Large-scale behavior emerges—and may be desirable—but this type of SoS should rely upon relatively invisible mechanisms to maintain it.
Collaborative	In collaborative SoS, the component systems interact more or less voluntarily to fulfill agreed upon central purposes. The Internet is a collaborative system. The Internet Engineering Task Force works out standards but has no power to enforce them. The central players collectively decide how to provide or deny service, thereby providing some means of enforcing and maintaining standards.
Acknowledged	Acknowledged SoS have recognized objectives, a designated manager, and resources for the SoS; however, the constituent systems retain their independent ownership, objectives, funding, and development and sustainment approaches. Changes in the systems are based on collaboration between the SoS and the system.
Directed	Directed SoS are those in which the integrated SoS is built and managed to fulfill specific purposes. It is centrally managed during long-term operation to continue to fulfill those purposes as well as any new ones the system owners might wish to address. The component systems maintain an ability to operate independently, but their normal operational mode is subordinated to the central managed purpose.

U.S. Department of Defense's Definitions of FoS

Defense Acquisition Guidebook (DAG)-2006 Definition of FoS

- Is not considered to be a system per se.
- Does not create capability beyond the additive sum of the individual capabilities of its member systems.
- Basically a grouping of systems having some common characteristic(s). For example, each system in a FoS may belong to a domain or product lines (e.g., a family of missiles or aircraft).
- Lacks the synergy of a SoS.
- Does not acquire qualitatively new properties as a result of the grouping. In fact, the member systems may not be connected into a whole.

U.S. Department of Defense's Definitions of FoS

Interim Defense Acquisition Guidebook (DAG)-**2009** Definition of FoS

- A family of systems is a grouping of systems having some common characteristic(s).
- For example, each system in a family of systems may belong to a domain or product line (e.g., a family of missiles, aircraft, or situation awareness systems).
- In general, a family of systems is not considered to be a system per se because it does not necessarily create capability beyond the additive sum of the individual capabilities of its member systems.
- A family of systems lacks the synergy of a SoS.
- The family of systems does not acquire qualitatively new properties as a result of the grouping. In fact, the member systems may not be connected into a whole.

U.S. Department of Defense's Definitions of FoS

Systems Engineering Guide for Systems of Systems, v1.0, 2008 (References the CJCS Definition of a FoS)

- A set of systems that provide similar capabilities through different approaches to achieve similar or complementary effects.
- For instance, the war fighter may need the capability to track moving targets. The FoS that provides this capability could include unmanned or manned aerial vehicles with appropriate sensors, a space-based sensor platform, or a special operations capability. Each can provide the ability to track moving targets but with differing characteristics of persistence, accuracy, timeliness, etc.

INCOSE's Definitions of System and SoS

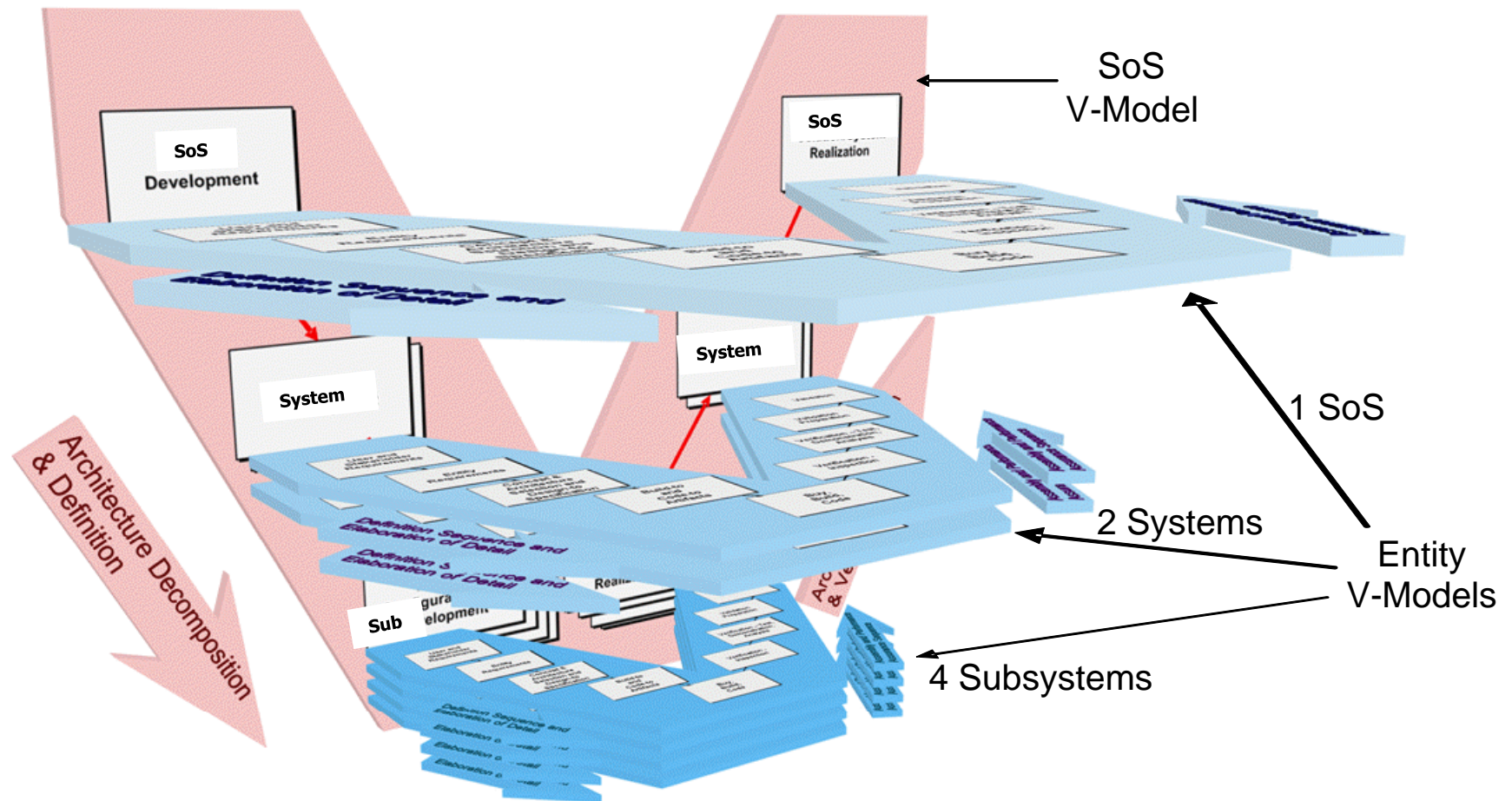
- A system is a combination of interacting elements organized to achieve one or more stated purposes.
- System of systems applies to a system-of-interest whose system elements are themselves systems; typically these entail large scale inter-disciplinary problems with multiple, heterogeneous, distributed systems.

Further simplification by myself leads to:

- System of systems applies to a system whose system elements are themselves systems.

V-Model Example for a System of Systems

CSM



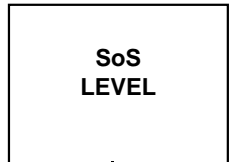
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Baselines, Documents, and Reviews for a SoS – My Perspective

J Clark

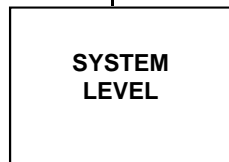
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Document Types:	ORD/ ICD	S/SS IRS	S/SS IRS S/SDD	SDD HDD IDD DBDD			SDD HDD IDD DBDD	T Plan T Proc	T Rpt	Rpt	Rpt	Rpt



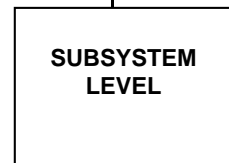
SoS Requirements Baseline	ASoSR △	SoSRR △	SoSFR △	SoSPDR △	ISoSR △
	ORD/ ICD	SoSS IRS	SoSS IRS	SoSDD	

SoS
requirements
allocated to
system



SoS Allocated Baseline =
System Requirements Baseline

System
requirements
allocated to
subsystem



System Allocated Baseline =
Subsystem Requirements Baseline

Rqmts
flow
down:

SRR △	SFR △	SPDR △	ISR △
SS IRS	SS IRS	SDD	

Rqmts
flow
down:

SubRR △	SubFR △	SubPDR △	SubCDR △	SubTRR △	SubTCR △	SubFCA △	SubPCA △
SubRS IRS	SubRS IRS	SubDD IDD DBDD	SubDD IDD DBDD	SubT Plan SubT Proc	SubT Rpt	Rpt	Rpt

Roll
up:

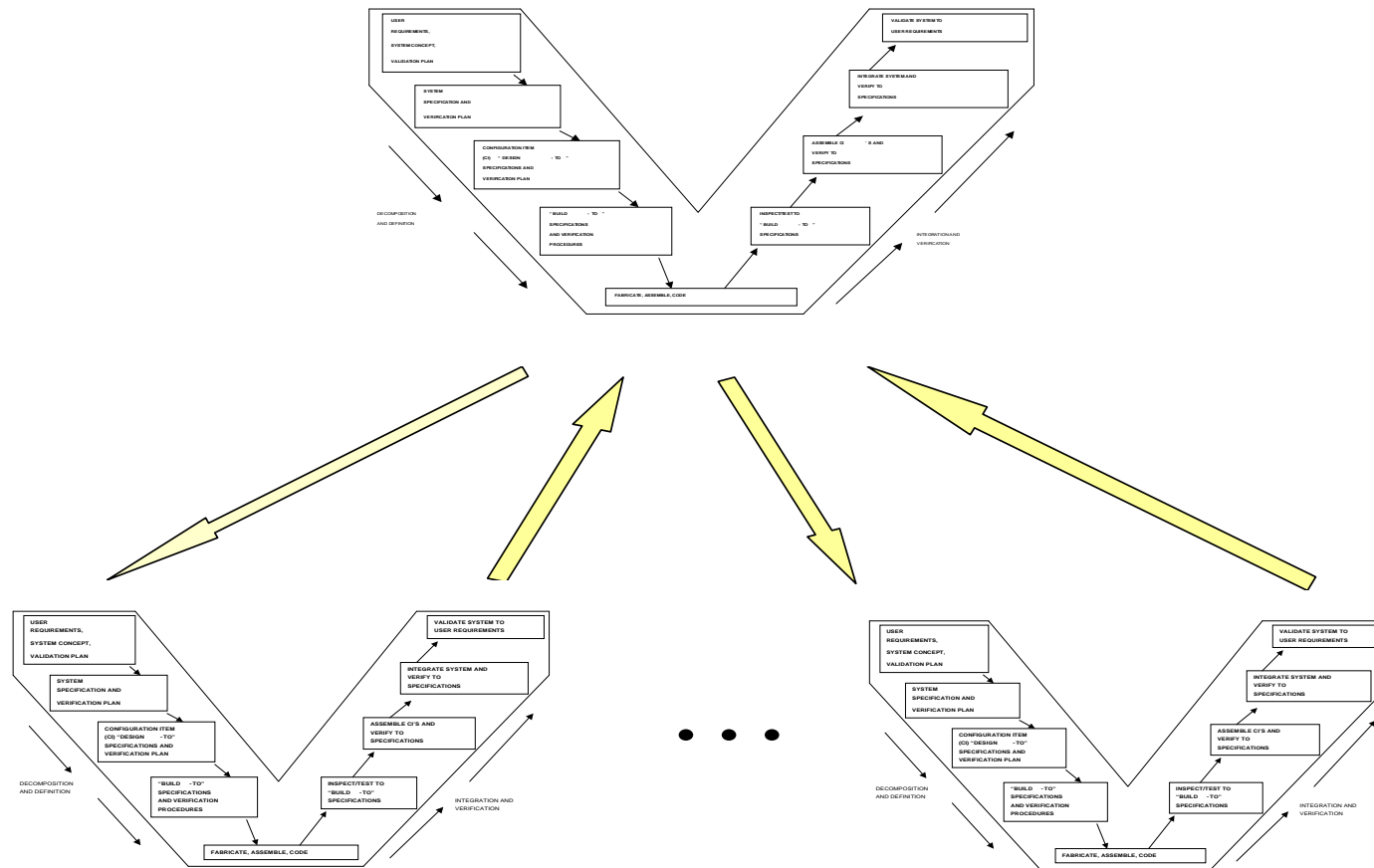
SoSCDR △	SoSTRR △	SoSTCR △	SoSVR △	SoSPCA △
SoSDD	SoST Plan SoST Proc	SoST Rpt	Rpt	Rpt
SCDR △	STRR △	STCR △	SFCA △	SPCA △
SDD	ST Plan ST Proc	ST Rpt	Rpt	Rpt

Roll
up:

V-Model Example for a System or SoS – My Perspective

J Clark

Incorrect V-Model



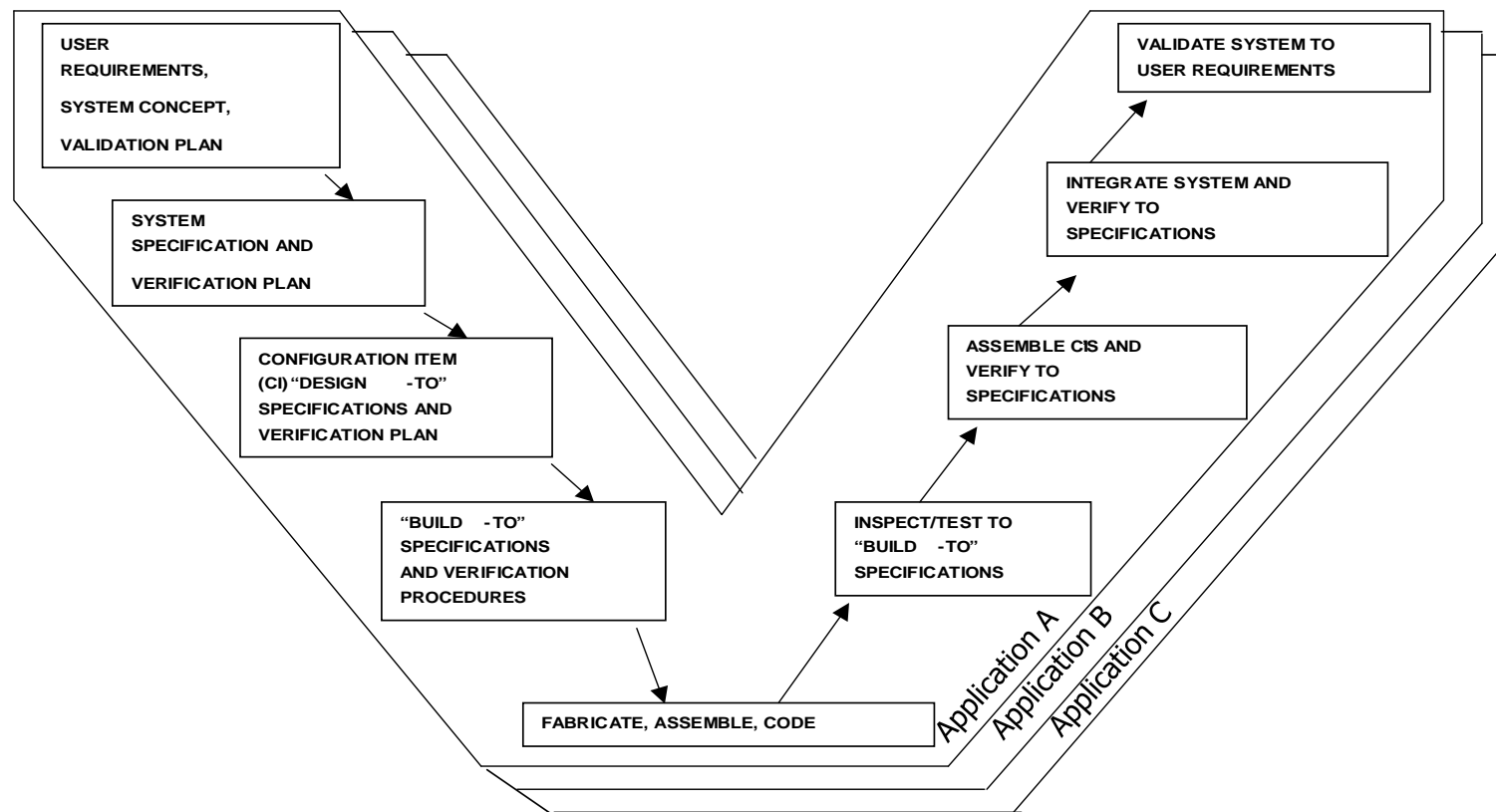
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V-Model Example for a FoS – My Perspective

K Forsberg

J Clark

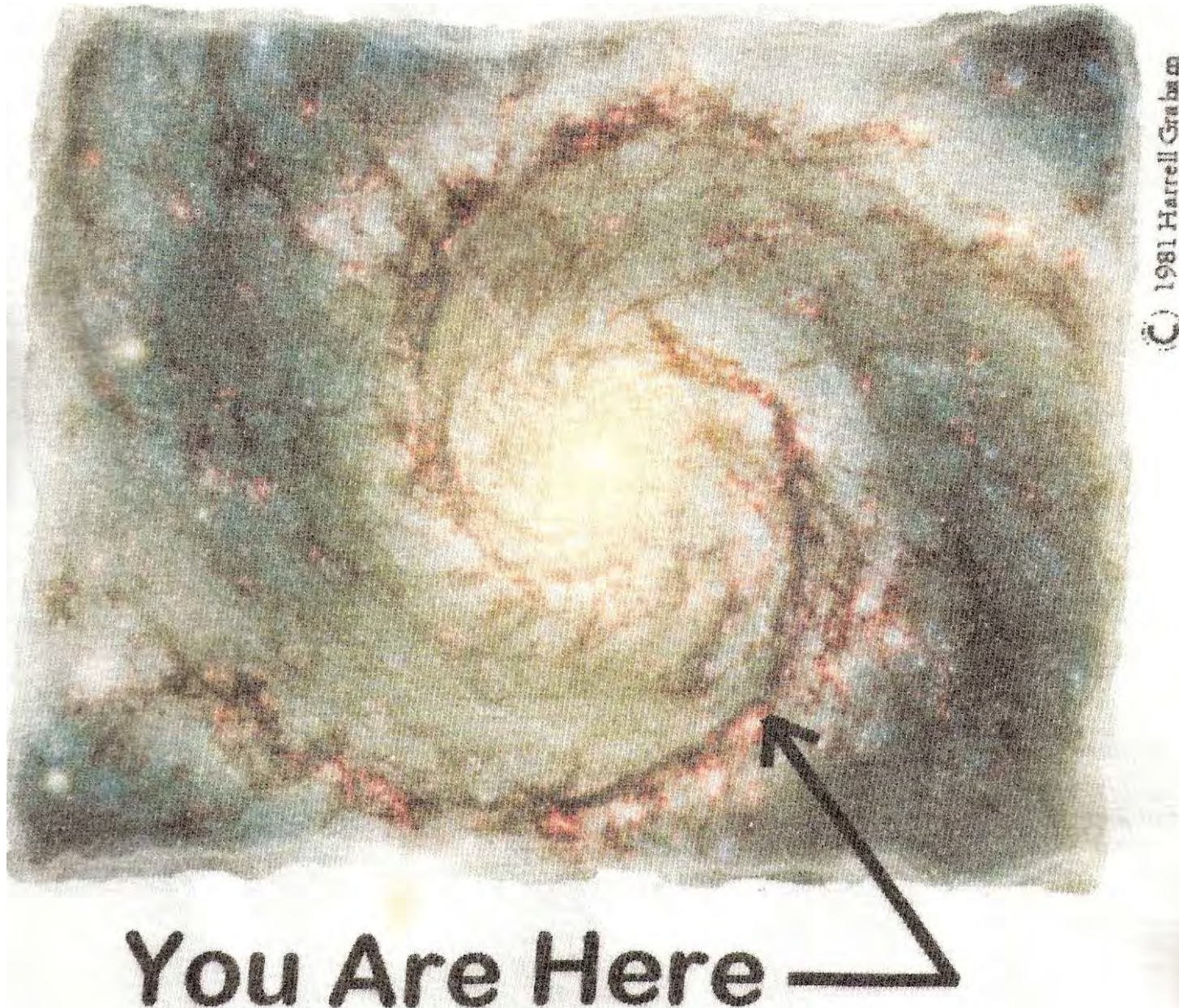
FoS V-Model



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Systems Thinking - My Perspective

J Clark



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Systems Thinking – My Perspective (cont)

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- Everything and everyone (from the universe to the nucleus of an atom) is a system, a SoS, and a subsystem of a higher-order system
- Everything and everyone that exists/existed (things, people, thoughts, sayings, writings, actions, etc.) uses/used the systems engineering process
- You see everything and everyone as a system, a SoS, a subsystem of a higher-order system, and a member of a FoS
- You “Stand on the standards”
- You have “The Knack”

Conclusion – My Perspective

J Clark

- Is engineering a SoS really any different from engineering an ordinary system?
- Some believe that SoSE is “different” from SE, the SE processes are inadequate or insufficient for SoSE, and additional processes are needed.
- Others, like me, believe the SE processes as documented in the SE process standards, and as illustrated in the V-Model and Dual-V Model, are a necessary and sufficient set of processes for SoSE, and no additional processes are needed. If you disagree, please get involved in the SE standards working groups and help us fix them. What is needed is additional guidance on how to apply these SE processes to SoSE.

Summary

J Clark

- Introduction
- Systems Engineering Views
- What is Different About SoSE and FoSE?
- Building Block
- V-Model
- Technical Baselines, Documents, and Reviews for a System
- Simple Definitions of SoS and FoS
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- V-Model Example for a System of Systems
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THE END!

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BACKUP

Not in the IEEE Paper

Hypotheses, Challenges, and Objectives

J Clark

- Hypotheses:
 - The SE Standards and V-Models describe the SE processes very well.
 - The SE Standards and V-Models contain a necessary and sufficient set of SE processes for solving complex SE and SoSE/FoSE problems.
 - Apply the SE Standards and V-Model processes that we already have to these problems, they will work.
 - The technical (SE Standards and V-Model) processes are adequate, the management (e.g., DoD acquisition) processes are not
- Challenges:
 - Communicate what the SE Standards and V-Models say about the SE processes for solving complex SE and SoSE/FoSE problems.
 - Gain consensus on what the SE Standards and V-Models say.
 - Convince stakeholders to read, understand, tailor, and apply the SE Standards and V-Models to solve these problems.
 - Obtain help to correct the SE Standards and V-Models if they're inadequate.
- Objectives:
 - Describe SE, SoSE, and FoSE from the SE Standards and V-Models perspective / view (EIA/IS-632, IEEE 1220, EIA-632, ISO 15288, Dr Kevin Forsberg)
 - Demonstrate that these SE standards and V-Models contain a complete set of SE processes for complex SE and SoSE/FoSE problems, and no additional processes are necessary
 - Show how to apply these SE standards and V-Models
 - Promote "Systems Thinking"